Physicists create clouds of impenetrable gases that bounce off each other

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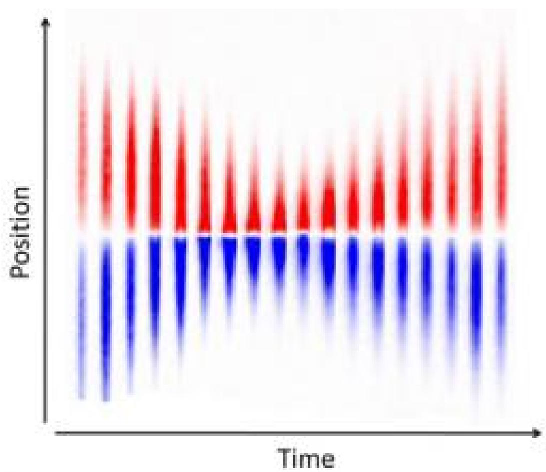

Two gas clouds (one red and one blue), each a million times thinner than air, are seen to completely repel each other under the influence of strong, quantum-mechanical interactions. Such gas clouds can model matter under extreme conditions, such as neutron stars or the quark-gluon plasma of the early universe. Image: Martin Zwierlein

(PhysOrg.com) -- When one cloud of gas meets another, they normally pass right through each other. But now, MIT physicists have created clouds of ultracold gases that bounce off each other like bowling balls, even though they are a million times thinner than air — the first time that such impenetrable gases have been observed.

While this experiment involved clouds of lithium atoms, cooled to near absolute zero, the findings could also help explain the behavior of similar systems such as neutron stars, high-temperature superconductors, and quark-gluon plasma, the hot soup of elementary particles that formed immediately after the Big Bang. A paper describing the work will appear in the April 14 issue of *Nature*.

The researchers, led by MIT assistant professor of physics Martin Zwierlein, carried out their experiment with an isotope of lithium that belongs to a class of particles called fermions. All building blocks of matter — electrons, protons, neutrons and quarks — are fermions.

Different states of fermionic matter are distinguished by their mobility. For example, electrons can be mobile, as in a metal; immobile, as in an insulator; or flow without resistance, as in a superconductor. However, for many types of material, including high-temperature superconductors, it is not known what circumstances induce fermions to form a given state of matter. This is especially true of materials with strongly interacting fermions, meaning they are more likely to collide with each other (also called scattering).

In this study, the researchers set out to model strongly interacting systems, using lithium gas atoms to stand in for electrons. By tuning the lithium atoms' energy states with a magnetic field, they made the atoms interact with each other as strongly as the laws of nature allow, meaning that they scatter every time they encounter another atom.

To eliminate any effects of heat energy, the researchers cooled the gas to about 50 billionths of one Kelvin, close to absolute zero (-273 degrees Celsius). They used magnetic forces to separate the gas into two clouds, labeled "spin up" and "spin down, then made the clouds collide in a trap formed by laser light. Instead of passing through each other, as gases would normally do, the clouds repelled in dramatic fashion.

"When we saw that these ultra dilute puffs of gas bounce off each other, we were completely amazed," says graduate student Ariel Sommer, lead author of the *Nature* paper.

The gas clouds did eventually diffuse into each other, but in several cases it took an entire second or more — an extremely long time for events occurring at microscopic scales.

The research, conducted at the MIT-Harvard Center for Ultracold Atoms, is part of a program aimed at using ultracold atoms as easily controllable model systems to study the properties of complex materials, such as high-temperature superconductors and novel magnetic materials that have applications in data storage and improving energy efficiency.

In future work, the researchers plan to confine the lithium gases to two-dimensions, which will allow them to simulate the two-dimensional state in which electrons exist in high-temperature superconductors.

Their work can also be used to model the behavior of other strongly interacting systems, such as high-density neutron stars, which are only a few tens of kilometers in diameter but more massive than our sun.

Another substance that interacts as strongly as the atoms in the ultracold lithium gas clouds created at MIT is quark-gluon plasma, which existed at the universe's formation and has been recreated in particle colliders by colliding atomic nuclei at energies corresponding to a trillion degrees.

More information: www.nature.com/nature/journal/ … ull/nature09989.html

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